

# Effect of Moisture Content on Some Physical Properties of Grains

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TWO important measurements used in determining the market grade of grain are moisture content and test weight per bushel (bulk density). Information on both test weight and moisture content is used in management decisions relative to conditioning, storing, and marketing of grain.

The basic physical properties of the grain depend on the variety and type of grain, the location and soil fertility where the crop is grown, and the cultural and harvesting practices used. Kernel size and shape, bulk density, true density, and porosity are parameters used in studying hydrodynamic, aerodynamic, and heat and mass transfer problems in grain. Both physical and chemical changes in grains are related to environmental factors encountered in the field and in storage after the grain is harvested. Physical properties are affected by the treatment grain receives. For example, Bushuk and Hlynka (2)\* found considerable hysteresis in weight and volume changes in wheat during adsorption and desorption of moisture.

The flow of fluids through beds of grains, as well as the mechanical and bulk flow properties of grain itself, depend on the manner in which grains are packed and the amount of air void within the packed bed. Zink (8) and Lorenzen (3) evaluated the porosity of grains by the liquid displacement technique. Recently, Thompson and Isaacs (5) determined the porosity of grains with the air-comparison pycnometer.

Particle shape influences void volume. Although many investigations have been aimed at quantitatively defining the shape of irregular particles, no universally accepted definition has yet been developed. Perhaps the term "sphericity" has been used most to describe particle shape. Seemingly the term was first used by Wadell (7), who

defined sphericity as the ratio of the surface area of a sphere to that of a given particle when both have the same volume. Later, Brown and Associates (1) developed Wadell's original concept of sphericity to its fullest by considering sphericity as a parameter to characterize flow through particle beds and around various geometrical shapes.

The purposes of this investigation were: To provide additional data on physical properties of corn and wheat; to study the changes in these properties caused by changes in moisture content related to both adsorption and desorption of moisture; and to examine the effect of kernel shape and size on corn packing characteristics.

## Materials and Methods

Four lots of Hard Red Winter wheat and two lots of yellow corn were used in these investigations. The wheat was obtained from country elevators at four different locations in Kansas during the 1965 and 1966 harvest. Initial moisture content of the four lots of wheat ranged from 11.7 to 13.4 percent w.b. The corn used was from the 1967 crop and was field shelled at moisture contents of 24 to 28 percent. The corn was used in refrigerated and aerated bulk storage tests where it was maintained at temperatures of 35 and 40 F until the moisture content was reduced to between 11 and 15 percent. Sample lots from this corn were used in the test evaluations.

Official grading procedures and

equipment (6) were used to remove dockage and foreign material from the grain before the measurement and evaluation of physical properties. A cylinder grader was used to size the corn into six separate classifications based on kernel thickness and width. Table 1 shows the percent by weight in each classification in one test lot of corn. The average volume and weight of kernels in each classification is also given.

About 2 qts of grain were used in each test. This amount was adequate for a moisture test with an electric moisture meter and for a standard test weight determination (6). To determine porosity, a small subsample was removed by a sample divider. Porosity was evaluated by an air-comparison pycnometer (Beckman Model 930).†

The true volume of a corn sample was also determined from the pycnometer measurements. The void space was the difference between the bulk volume and the true volume. Void space frequently is used as an index of porosity. The true density ( $\rho_T$ ) and bulk density ( $\rho_B$ ) were calculated from the weight and volume measurements. Then the porosity ( $\epsilon$ ) was calculated as follows:

$$\epsilon = 1 - \frac{\rho_B}{\rho_T} \quad [1]$$

For this porosity ( $\epsilon$ ), the sphericity of the sample was evaluated from data by Brown (1) that related sphericity to porosity.

Tests were made with wheat at mois-

TABLE 1. SIZE CLASSIFICATION OF 12 PERCENT MOISTURE YELLOW CORN AND THE AVERAGE KERNEL WEIGHT AND VOLUME RELATIONSHIP IN EACH CLASSIFICATION

Fraction of sample	Size, in. A = width B = thickness	Quantity per fraction, percent	Kernel		
			Weight, g	Volume, cu cm	Weight per unit volume, g per cu cm
Small small flat	17/64 < A < 21/64 B < 11.5/64	24.9	0.267	0.207	1.29
Small medium flat	17/64 < A < 21/64 B < 12.5/64	8.7	0.294	0.228	1.29
Large medium flat	21/64 < A < 28/64 B < 12.5/64	41.1	0.341	0.261	1.31
Large flat	21/64 < A < 28/64 B < 14.5/64	9.1	0.382	0.288	1.33
Small round	17/64 < A < 21/64	7.3	0.309	0.239	1.29
Large round	21/64 < A < 28/64	5.6	0.402	0.311	1.29
Miscellaneous Residue		3.3	—	—	—

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\* Numbers in parentheses refer to the appended references.

ture contents ranging from 9 to 19 percent, and with corn at moisture contents ranging from 9 to 27 percent. Each experiment was replicated once, and all measurements were repeated three times. The moisture levels of wheat and classified corn were first increased by exposing the samples, in perforated pans, to the moist air in an environmental chamber until the moisture reached about 19 percent w.b. For the desorption path, the samples were exposed to atmospheric conditions in the laboratory until the moisture levels decreased to about 9 percent w.b. When the desired approximate moisture level was reached, the samples were placed in plastic bags and left overnight at room temperature before the measurements were taken. For the mixed corn sample, the changes in properties were examined first by the desorption path, then by the adsorption path, in the same manner as described above.

## Results and Discussion

The change in test weight associated with the change in moisture content for one lot of wheat is shown in Fig. 1. The data for the other three lots of wheat were similar. The relationship between test weight and moisture content in yellow corn is shown in Fig. 2. The dashed and solid curves in Figs. 1 and 2 represent test weight changes for adsorption and desorption paths, respectively.

A small hysteresis existed between the test weights measured at moisture levels along with the adsorption and desorption paths. For wheat at the lower moisture content level, the test weight on the adsorption path was above that for the desorption; when the moisture was above 16 percent, test weight for the adsorption path became lower than the desorption path. Bushuk and Hlynka (2) observed a similar phenomenon. For corn, the test weight for the adsorption path was always higher than that for the desorption path in the moisture range tested.

The hysteresis effect on test weight was more pronounced for corn than for wheat. For example, the maximum differences in test weight between the adsorption and desorption paths was about 0.4 lb per bu for wheat and a little more than 2 lb per bu for corn. All wheat samples decreased in test weight as the moisture content increased. The decrease in test weight was about 5 lb per bu for a moisture change of from 9 to 19 percent. The rate of change in test weight was quite slow at the lower moisture contents. For the adsorption path, little or no change in test weight was observed at moisture contents below 11 percent. These results with wheat are compar-

able to those reported by Lorenzen (3).

The change in test weight of corn associated with the moisture content change was different from that of wheat. Fig. 2 shows that as the corn dried from 27 to about 23 percent moisture content, the test weight decreased, then increased with further drying. This result was also observed by Miles (4), but the moisture content at which the minimum test weight occurred in his tests was different. The total test weight change of the corn sample was about 7 lb per bu for the moisture range tested, which was 9 to 27 percent.

Along the adsorption path, although the test weight of corn showed little change in the 9 to 12 percent moisture range, it decreased as the moisture content increased above 12 percent. This experiment for the adsorption path was not carried beyond a moisture content of 19 percent because mold developed on the corn. For the same moisture content, the test weight of corn in these tests was lower than that used by Lorenzen (3) and Miles (4), but about the same as that for some varieties listed by Thompson and Isaacs (5).

The test weight changes in six classifications of corn were observed at moisture contents ranging from about 12 percent to 18.5 percent along the adsorption path. The effect of size and shape of corn kernels on the test weight is plotted in Fig. 3. For each kernel size and shape classification, the corresponding test weights were ranked in the following order: Large flat > large medium flat > small medium flat > large round > small small flat > small round. In general, the test weight of the flat kernels was higher than that of the round kernels, and the test weight of the larger kernels was higher than that of the smaller kernels.

There are two possible explanations for the higher test weights of corn that includes only large or medium flat kernels. First, according to the data in Table 1, the larger flat kernels have a greater true density. Given a bulk with some void space, the bulk density (test weight) would be higher if the true density of the particles were higher. A second possible explanation could lie in the "plate-like" or "disk-like" shape of the kernels, which permits more of them, by random arrangement, to lie parallel like stacked plates or logs and thus reduce the void space in the bulk.

A comparison of the test weight of corn kernels of mixed sizes and shapes with kernels having uniform size and shape showed that the test weights of mixed kernels were considerably lower. The rate of test weight change with respect to the moisture content change was almost twice as much for the mixed

corn sample as for the uniform size and shape sample.

The relationship between test weight and moisture content was curvilinear for both wheat and corn. The data were linearized by converting the test weight into dry matter weight per

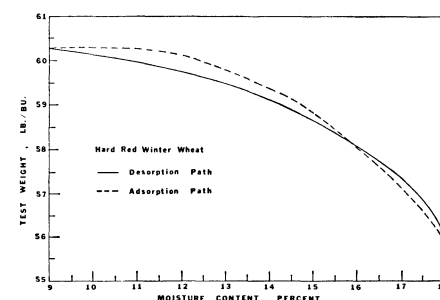


Fig. 1 Test weight of hard red winter wheat for adsorption and desorption paths as moisture content changes

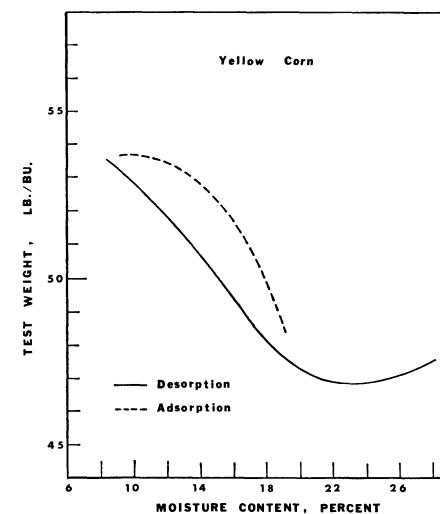


Fig. 2 Test weight of yellow corn for adsorption and desorption paths as moisture content changes

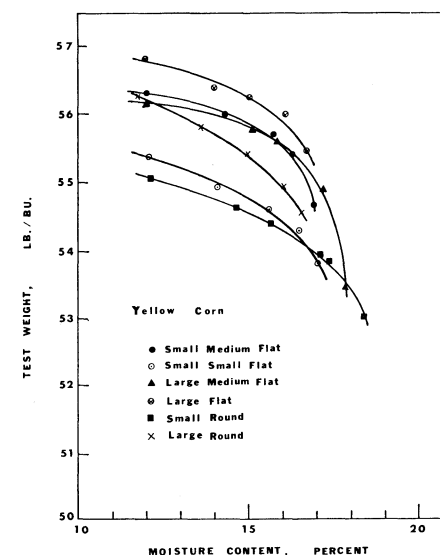


Fig. 3 The effect of size and shape of corn kernels on test weight as moisture content changes

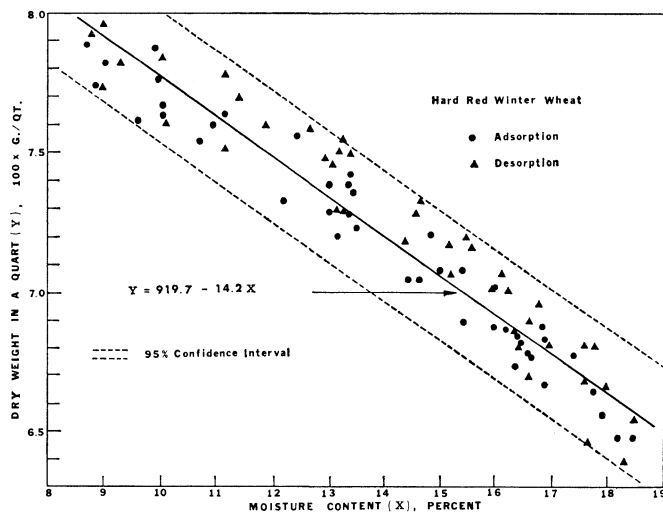


Fig. 4 Relationship between the weight of dry matter in a quart of hard red winter wheat and the moisture content of the wheat

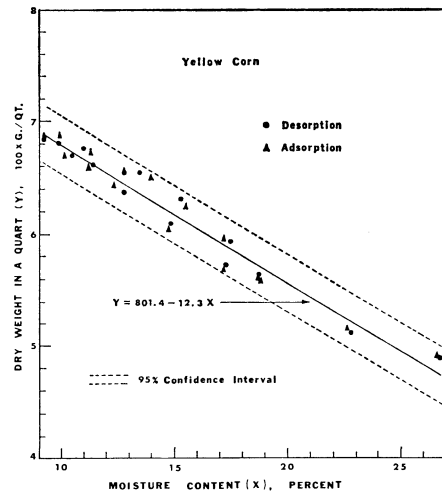


Fig. 5 Relationship between the weight of dry matter in a quart of yellow corn, and the moisture content of the corn

quart. The dry matter weight per quart was plotted against the moisture content for wheat samples in Fig. 4, and for corn samples in Fig. 5. All data were pooled since statistical tests based on the dry matter weight per quart showed no significant difference between the two replications, the adsorption and desorption paths, and the sample lots.

The correlation coefficients between the dry matter weight per quart and the moisture content was  $-0.96$  for wheat and  $-0.98$  for corn. The regression equations of this relationship for wheat and corn are:

$$\text{Wheat: } Y = 919.7 - 14.2 X \quad [2]$$

$$\text{Corn: } Y = 801.4 - 12.3 X \quad [3]$$

where  $Y$  is the weight in grams of dry matter in a quart (g/qt), and  $X$  is the percent moisture. For wheat, the standard deviation from regression was 10.90 g/qt, and for corn, 12.46 g/qt.

All data were within the 95 percent confidence interval which is shown by the dashed lines in Figs. 4 and 5.

Equations [2] and [3] were converted into pounds per bushel to give a general estimate of test weight. For a given moisture content, the test weight of the wheat and corn used in these tests can be estimated by the following equations:

Wheat: estimated test weight =

$$(64.9 - X) \frac{100}{100 - X} \quad [4]$$

Corn: estimated test weight =

$$(56.5 - 0.87 X) \frac{100}{100 - X} \quad [5]$$

True densities of wheat and corn at various moisture contents, evaluated by the air comparison pycnometer, are shown in Fig. 6. (True density is expressed in pounds per cubic foot instead of pounds per bushel as used in the discussion on test weight.) The mass-to-volume ratio of the wheat ker-

nels was higher than that of the corn kernels. Even though some decrease in the true density was observed with increasing moisture contents, the change was small as compared with the change in bulk density, especially for corn.

The regression equations for the relationship between true density ( $\rho_T$ ) in lb per cu ft and moisture content in percent are:

$$\text{Wheat: } \rho_T = 90.11 - 0.163 X \quad [6]$$

$$\text{Corn: } \rho_T = 82.89 - 0.10 X \quad [7]$$

The standard deviations from the regression are 0.72 lb per cu ft for wheat and 0.40 lb per cu ft for corn.

Information on bulk density or porosity should include some indication of the degree of packing; i.e., normal, loose, or dense. The degree of packing was considered to be normal by the method employed in this investigation.

In Fig. 7, the porosities of wheat and corn at various moisture contents are plotted against the corresponding bulk densities. The relationship is linear and the regression equations for the wheat and corn samples are:

$$\text{Wheat: } \epsilon = 0.90 - 9.3 \times 10^{-3} \rho_B \quad [8]$$

$$\text{Corn: } \epsilon = 1.01 - 1.25 \times 10^{-2} \rho_B \quad [9]$$

where  $\epsilon$  is porosity in fraction, and  $\rho_B$

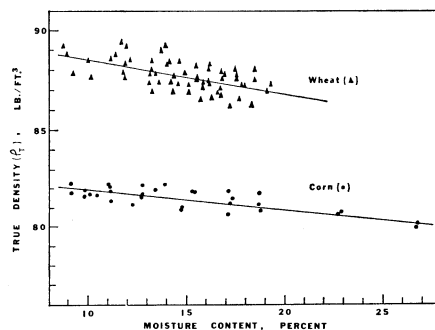


Fig. 6 True density of hard red winter wheat and yellow corn as moisture content changes

(bulk density) is in lb per cu ft. The standard deviations from the regression are 0.001 for wheat and 0.005 for corn.

According to equation [1], a plot of  $\epsilon$  versus  $\rho_B$  should be a straight line with an intercept of 1 and a slope of  $1/\rho_T$ . However, the results of regression analysis on the experimental data deviate somewhat from these conditions. The true densities measured did not remain constant over the moisture content ranges tested and, therefore, did not conform to conditions in equation [1]. Also, experimental errors in measuring the bulk and true density of the samples were partially responsible for the lack of agreement.

The porosity was low at high bulk densities and at low grain moisture contents. Corn kernels of uniform size and shape have less void space than non-uniform kernels. There was more void space in wheat than in corn at

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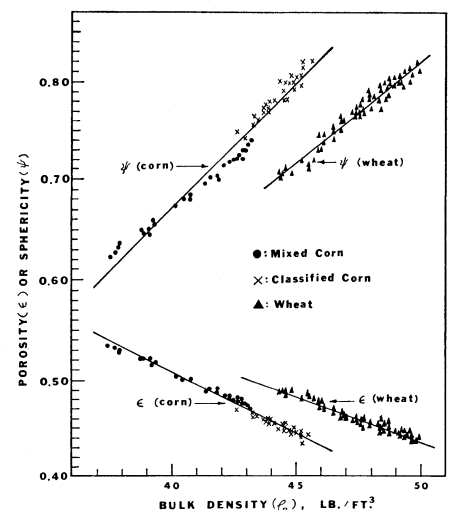


Fig. 7 Relationships between porosity and bulk density and between sphericity and bulk density for hard red winter wheat and yellow corn (1)

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the same bulk density, due mainly to the higher true density of wheat. For non-uniform size and shape particles, the smaller the particle size, the greater the probability of having more void space. Porosities evaluated in this investigation agreed with those reported by Thompson and Isaacs (5) for a similar bulk density range.

The sphericity of wheat and corn was evaluated by the relationship between sphericity and porosity based on normal packing, as given in reference (1). Values of sphericity read from the curve in reference (1) are plotted against bulk density in Fig. 7. The relationship yields a straight line for the range of bulk densities examined. The regression equations are:

$$\text{Wheat: } \psi = -0.193 + 2.02 \times 10^{-2} \rho_B \quad [10]$$

$$\text{Corn: } \psi = -0.35 + 2.55 \times 10^{-2} \rho_B \quad [11]$$

where  $\psi$  is the sphericity of grain in

fraction, and  $\rho_B$ , bulk density, is in lb per cu ft. The standard deviations from the regression are 0.007 for wheat and 0.012 for corn.

By the definition of sphericity, the negative value of sphericity should not exist and the sphericity of a perfect spherical particle should be unity. However, the regression equations obtained violate the above conditions for some bulk densities. This violation indicates that the relationship between sphericity and bulk density is not linear over the expected range of bulk densities. When the bulk density of the grain bed was high, its behavior was closer to that of a bed of spherical particles. For a given bulk density, the sphericity of corn was higher than that of wheat. The surface area or K-factor ( $S/V$ ) for wheat or corn kernels with known volume can be estimated from the sphericity value given in this report, since sphericity is defined as  $4\pi r_v^2/S$ , where  $r_v$  is the radius of a sphere occupying the same volume as the particle, and  $S$  is the surface area of the particle.

Within the limits of the test parameters used in this investigation, physical properties such as bulk density or test weight, true density, porosity, and sphericity can be approximated for wheat and corn at various moisture levels with the equations given.

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